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TECHNICAL NOTE
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EFFECTS OF CONTROL-RESPONSE CHARACTERISTICS

ON THE CAPABILITY OF A HELICOPTER

FOR USE AS A GUN PLATFORM

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Langley Field, Va.

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EFFECTS OF CONTROL-RESPONSE CHARACTERISTICS ON THE CAPABILITY OF A HELICOPTER FOR USE AS A GUN PLATFORM

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SUMMARY

An investigation with a variable-stability helicopter was undertaken to ascertain the steadiness and ability to "hold on" to the target of a helicopter employed as a gun platform. Simulated tasks were performed under differing flight conditions with the control-response characteristics of the helicopter varied for each task. The simulated gun-platform mission included: Variations of headings with respect to wind, constant altitude and "swing around" to a wind heading of 0°, and increases in altitude while performing a swing around to a wind heading of 0°.

The results showed that increases in control power and damping increased pilot ability to hold on to the target with fewer yawing oscillations and in a shorter time. The results also indicated that wind direction must be considered in accuracy assessment. Greatest accuracy throughout these tests was achieved by aiming upwind.

INTRODUCTION

In the past few years there has been considerable interest in using helicopters as gun platforms. From this interest there arose a need to know whether presently operational helicopters are adequately controllable to achieve the degree of accuracy necessary to execute a weapons firing mission. U.S. Army tests of firing accuracy have been tried at Fort Rucker, Alabama (ref. 1) under "pop-up" conditions, and the French Army has had actual battlefield experience with helicopters (ref. 2).

The Langley Research Center has employed a variable-stability helicopter for the study of flying qualities and handling characteristics of helicopters and low-speed configurations for several years. The problem areas have dealt particularly with the quantitative assessment of minimum control power and angular-velocity damping that would be desirable to assure the satisfactory achievement of precision tasks. Increased precision flying capability would be expected to result in wider applications than are currently considered feasible for helicopters.

Tests were conducted by varying the control-response characteristics of the variable-stability helicopter. A series of target-seeking tasks was used to determine the influence of the stability parameters. The tasks were limited to seeking and holding a stationary target at close range with a somewhat elementary aiming device under good visual flight conditions and moderate winds. The effects of wind direction were
included in the study by having the pilots seek the target around the L
azimuth at 90° intervals beginning from zero azimuth at the upwind 7
position. 9
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SYMBOLS

M_c	control moment per inch of stick deflection, ft-lb/in.
M_d	damping moment proportional to and opposing angular velocity, ft-lb/radians/sec
I	fuselage moment of inertia, slug-ft^2
θ	pitching angular displacement, radians
ϕ	rolling angular displacement, radians
ψ	yawing angular displacement, radians

Subscripts:

X	longitudinal body axis
Y	lateral body axis
Z	normal body axis

DEFINITIONS

control power	moment on helicopter produced for a given control displacement
damping	moment on helicopter proportional to and opposing angular velocity

DESCRIPTION OF TEST VEHICLE AND TASKS

Test Helicopter

All flights were performed with a variable-stability helicopter in which both the ratio of control moment to stick deflection, or control power, and the apparent angular-velocity damping were varied by the use of electronic components in the control system. A comprehensive description of the variable control system and the means of varying the control power and damping about the three principal inertia axes is presented in reference 3. The general physical characteristics of the test helicopter are listed in table I. Many present-day rotary-wing aircraft have ratios of control power to moment of inertia and damping to moment of inertia that are not as large in magnitude as those of the test helicopter in its unaltered configuration. Some of these aircraft are being considered for weapons-system platforms.

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The various combinations of control power and damping that were used in this series of tests are listed in table II. The test combinations are expressed in ratios of control power to moment of inertia and damping to moment of inertia about the three principal inertia axes. Figure 1, although not a precise representation about all three axes, shows the approximate combinations of control power and damping used in this series of tests. This figure groups the roll, pitch, and yaw values for a given test condition, and these groups are tabulated in terms of control-power and damping multiples of the basic helicopter configuration in table II.

The test vehicle was instrumented to record angular velocity about the principal inertia axes and pilot control positions. In addition, a gun camera was installed in the nose of the aircraft for visual indication of proficiency.

Test Maneuver

The primary maneuver required of the pilot was to hold the aircraft to a constant heading on a fixed target (hold on). As soon as the pilot had achieved a constant heading on the target, he would take records for quantitative data from which the best combinations of control power and damping for this task could be determined. The best combination would be evaluated from the steadiness, or the extent of unsteadiness, that appeared on the angular velocity and pilot control records. This task was, however, oversimplified for skillful pilots to such an extent that differences were too slight for accurate evaluation. Therefore, dynamic maneuvers enlarging the task to target seeking prior to target holding were added in order to assess the flying qualities of the helicopter notwithstanding the skill of the pilots.

The first series of tests is depicted graphically in figure 2(a). In this series the target was placed in four positions around the azimuth with respect to the relative wind to determine the extent of the effect of wind direction on target-holding ability.

The next series of tests is depicted in figure 2(b). In this series the pilot was required to swing around to the target at a constant alti-
tude, turning from left to right and always aiming upwind. Time his- L
tories from this series provide data for "come-on" rates, overshooting 7
the target, and a general assessment of the time required of the pilot 9
finally to bring the helicopter to a steady heading. 6

Figure 2(c) depicts the final series of tests in which the pilot was required to pop up to an altitude of approximately 50 feet while swinging around to the target as was done in the previous series shown in figure 2(b). The evaluation for this series is essentially the same as is used in the swing-around maneuver which is a comparison of the angular-displacement time histories. The pop-up feature served further to hinder the pilot in utilizing compensating techniques when the control-power and damping combinations were poor, and thus the differences are more clearly delineated in the time histories.

RESULTS AND DISCUSSION

Change in Direction Prior to Hold On Target

The effects of two test conditions (1/2 and 3 times the basic condition) are illustrated in figure 3. This figure is a time history of the angular displacement about all three axes with a wind velocity of approximately 12 knots and the helicopter turning upwind. The results show that with the control power and apparent angular-velocity damping increased by a factor of 3 over the values for the basic configuration, the pilot was able to make a quick and positive 70° change in heading (fig. 3(a)) and also to hold the new heading without difficulty; similar beneficial effects were also noted by the pilot about the pitch and roll axes. When the control power and damping were reduced to 1/2, the handling characteristics were very poor; a great deal more effort and time were required of the pilot to hold on to his target than with the combination of 3 times control power and damping, which is considered the best of the variations tested. The erratic yawing motion following a 70° change in heading shows up clearly in the figure in the case where control power and apparent damping were reduced to 1/2 of the values of the basic helicopter configuration.

Change in Altitude and Direction Prior to Hold On Target

Figure 4 illustrates time histories of the pop-up and swing-around maneuver using 1/2 of the values of the basic configuration for control power and damping and 3 times control power and damping. The most significant motion appeared about the yaw axis rather than about the roll and pitch axes. Through the use of the high control-power and damping combination, the pilot reached a come-on rate (that is, angular velocity before he reversed control to go back to the target) of 9° per second. This combination also permitted the pilot to shorten the time it took to hold on to the target by 2 seconds. With the lowest values of control power and damping, a come-on rate of 3.8° per second was achieved and a longer period of time for hold on. According to reference 4, the slower come-on rate would be inadequate for most maneuver situations.

Effect of Relative Direction of Wind on Ability to Hold On Target

The hold-on target tests were performed to evaluate the effects of heading under the least difficult conditions. The effect of heading on these results may be seen in figure 5. The figure shows typical yaw-velocity time histories at four headings. In this case control power was 2 times the values of the basic configuration and damping was 2 times basic. The greatest steadiness was acquired at a heading of 0° to the relative wind. This fact was confirmed by pilot opinion. Better results could undoubtedly be achieved with available military sighting devices.

Pilot Opinion of Test Combinations

The test combinations of 1/2 basic control power and 3 times basic damping (test 6 in table II) was such that the aircraft was slow to arrive on target but easy to hold once there. According to pilot opinion, 3 times basic control power and 3 times basic damping (test 7 in table II) provided a satisfactory combination of both these parameters. The high damping and control power provided a rapid come on to target and the aircraft was easy to hold to a steady heading. Pilot opinion of high control power and low damping was that with this combination, the aircraft was difficult to hold on target. The test condition of 1/2 basic control power and 1/2 basic damping (test 4 in table II) was generally considered as having the poorest combination of damping and control power used. This variation gave a slow swing around and the helicopter was difficult to hold on target.

CONCLUDING REMARKS

An investigation of the effects of various combinations of control power and damping on the steadiness and ability to hold on to a target during hovering has been conducted. The improvement in handling qualities for tasks which include pop up and swing around to hold on a target have been shown with increases in control power and damping.

The control-response characteristics of the basic test vehicle are
similar to the characteristics of helicopters now in service, and the L
variations, therefore, that have been put into the control system form 7
a general basis for improvement available for other aircraft in the same 9
general weight class. Many of the aircraft presently considered for 6
gun-platform applications have lower control-power and damping values than the basic values of the test helicopter. Improved aiming accuracy should be achieved with increased stability for aircraft now under consideration as has been achieved with increased control power and damping for the test helicopter.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 13, 1960.

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2. Pierpoint, T. R., and Geier, L. J.: French Army H-21 Helicopter Operations in Algeria. Proc. Thirteenth Annual National Forum, Am. Helicopter Soc., Inc., May 8-11, 1957, pp. 129-139.

3. Salmirs, Seymour, and Tapscott, Robert J.: Instrument Flight Trials With a Helicopter Stabilized in Attitude About Each Axis Individually. NACA TN 3947, 1957.

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TABLE I

PHYSICAL CHARACTERISTICS OF THE TEST HELICOPTER

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Gross weight, lb	5,500
Moments of inertia:	
Pitch, I_Y, slug-ft^2	7,000
Roll, I_X, slug-ft^2	2,000
Yaw, I_Z, slug-ft^2	5,000
Number of blades in main rotor	3
Rotor rotational speed, radians/sec	19.4
Rotor diameter, ft	48
Height of rotor hub with respect to center of gravity, ft	6.5
Blade mass factor	9
Control travel:	
Longitudinal cyclic, in.	13.6
Lateral cyclic, in.	13.6
Pedal, in.	4.75
Basic control power, M_c:	
Pitch, ft-lb/in. of control travel	508
Roll, ft-lb/in. of control travel	474
Yaw, ft-lb/in. of control travel	4,140
Basic damping, M_d:	
Pitch, ft-lb/radians/sec	2,495
Roll, ft-lb/radians/sec	2,495
Yaw, ft-lb/radians/sec	10,600

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TABLE II

EXACT VALUES OF TEST COMBINATIONS FOR RATIOS OF CONTROL POWER TO MOMENT OF INERTIA AND DAMPING TO MOMENT OF INERTIA ABOUT THE PRINCIPAL AXES

[Control power ratios in $\frac{\text{ft-lb/in.}}{\text{slug-ft}^2}$; damping ratios in $\frac{\text{ft-lb/radians/sec}}{\text{slug-ft}^2}$]

Test	Pitch		Roll		Yaw		Approx. multiples	
	$\frac{M_c}{I_Y}$	$\frac{M_d}{I_Y}$	$\frac{M_c}{I_X}$	$\frac{M_d}{I_X}$	$\frac{M_c}{I_Z}$	$\frac{M_d}{I_Z}$	Control power	Damping
Basic	0.07	0.66	0.24	1.25	0.83	2.12	1	1
1	.15	1.33	.36	3.74	1.66	4.24	2	2
2	.15	1.99	.36	3.74	1.24	6.36	1	3
3	.22	1.99	.47	3.74	1.66	6.36	2	3
4	.04	.33	.12	.62	.41	1.06	1/2	1/2
5	.22	.33	.71	.62	2.48	1.06	3	1/2
6	.04	1.99	.12	3.74	.41	6.36	1/2	3
7	.22	1.99	.71	3.74	2.48	6.36	3	3

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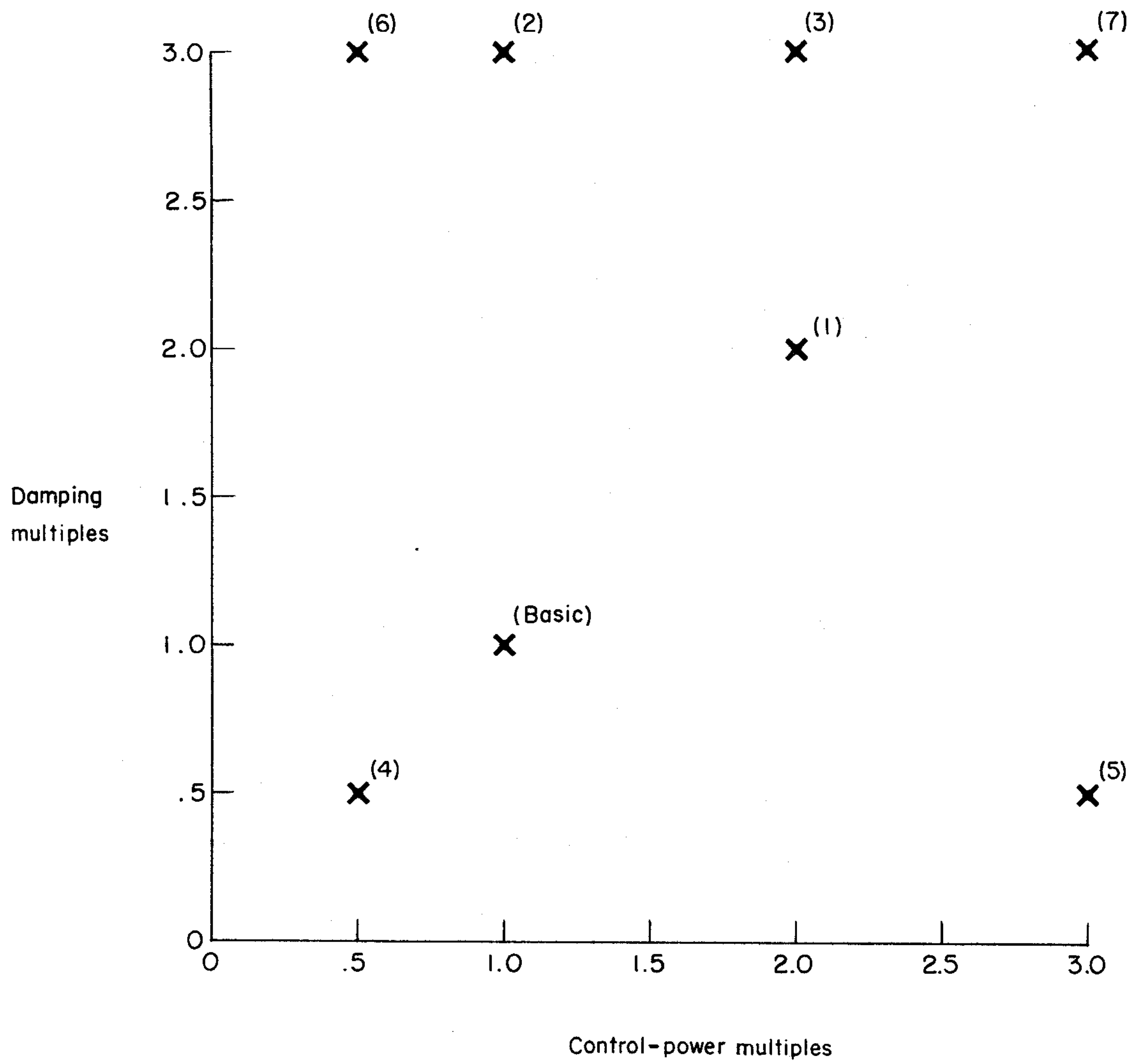
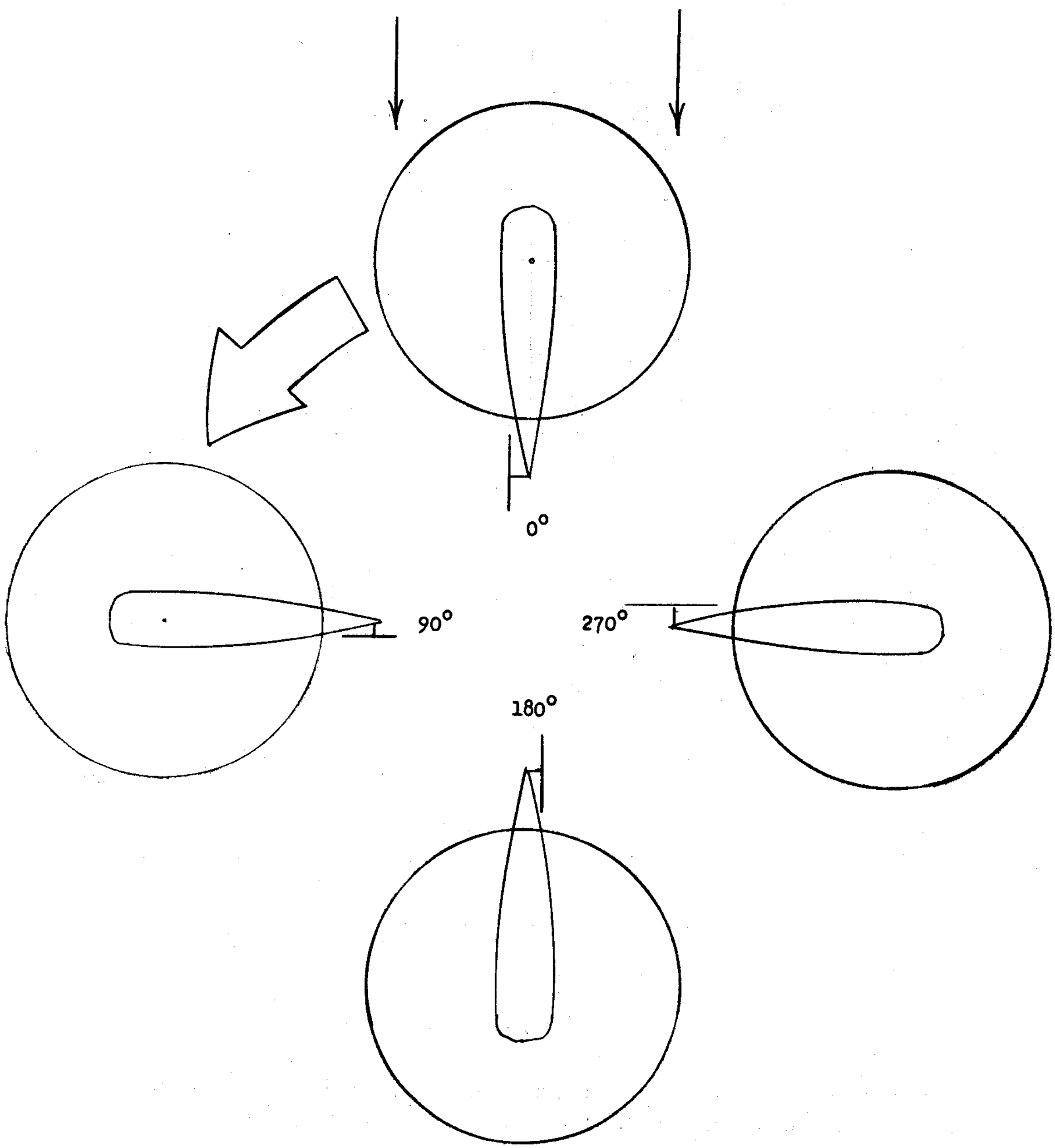


Figure 1.- Relative positions of test combinations as enumerated in table II in terms of multiples of the basic helicopter.



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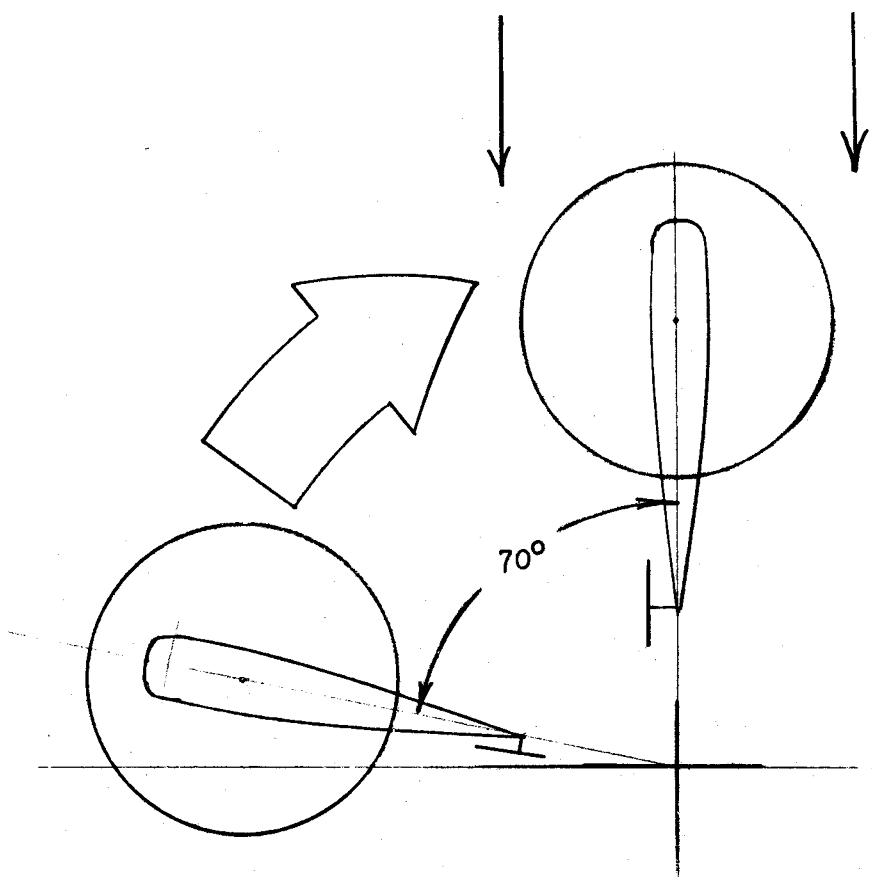
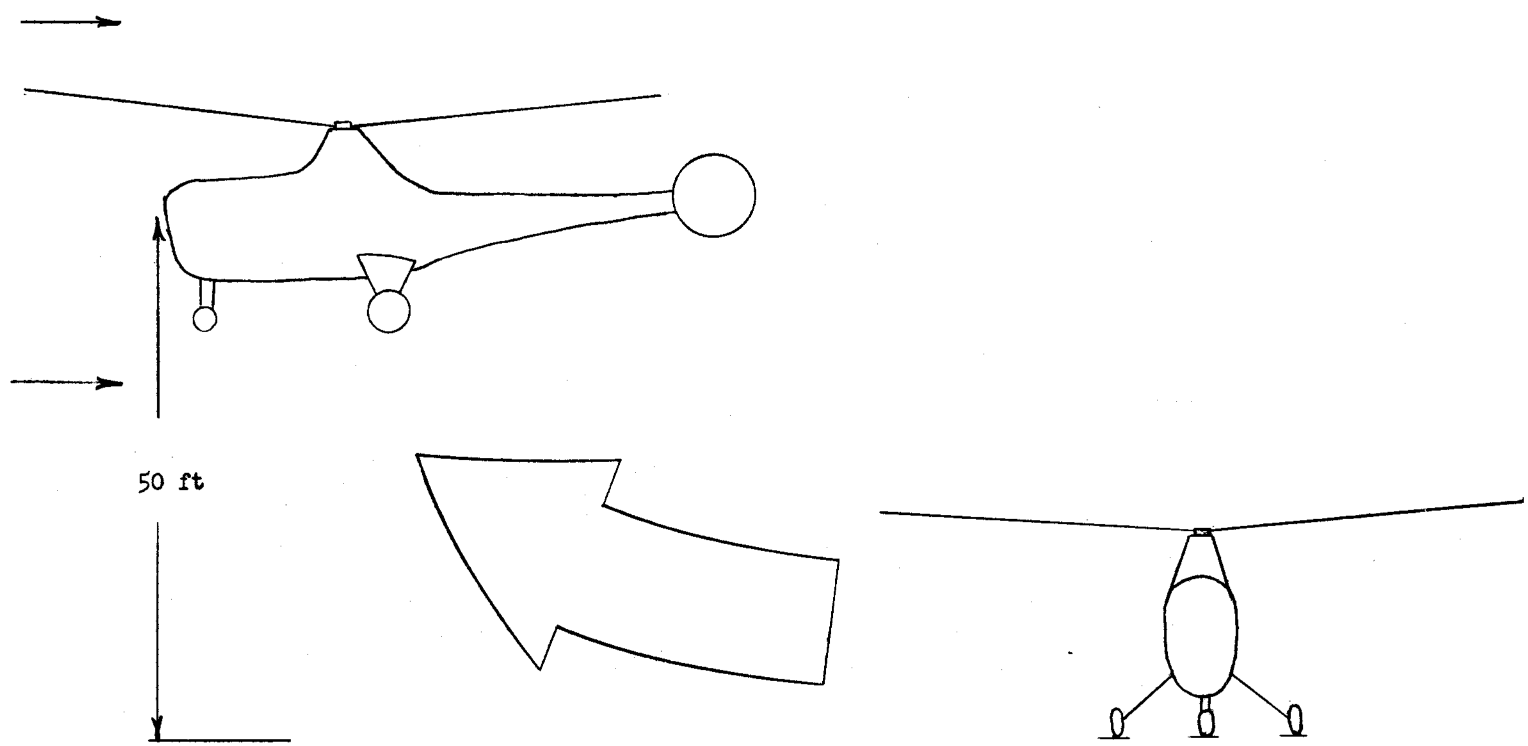
(a) Hold on to target.

Figure 2.- Test maneuvers.



(b) Swing around to target.

Figure 2.- Continued.



(c) Pop up and swing around to target.

Figure 2.- Concluded.

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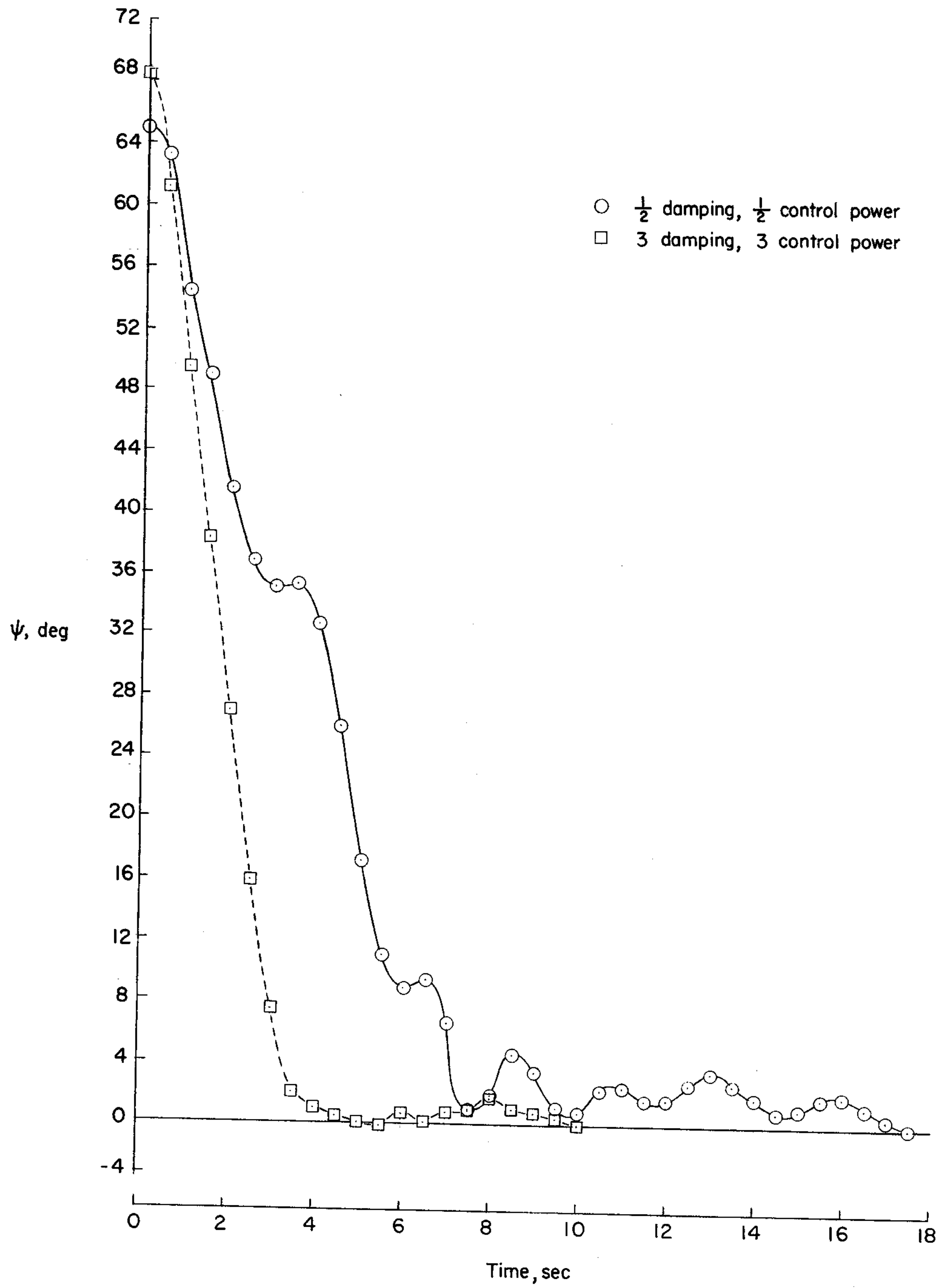
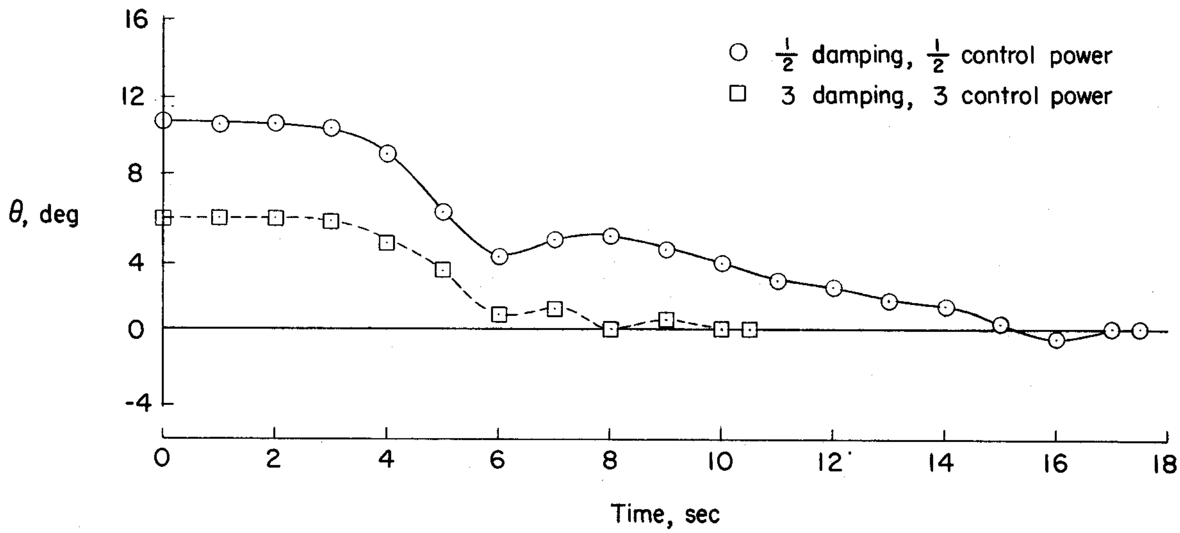
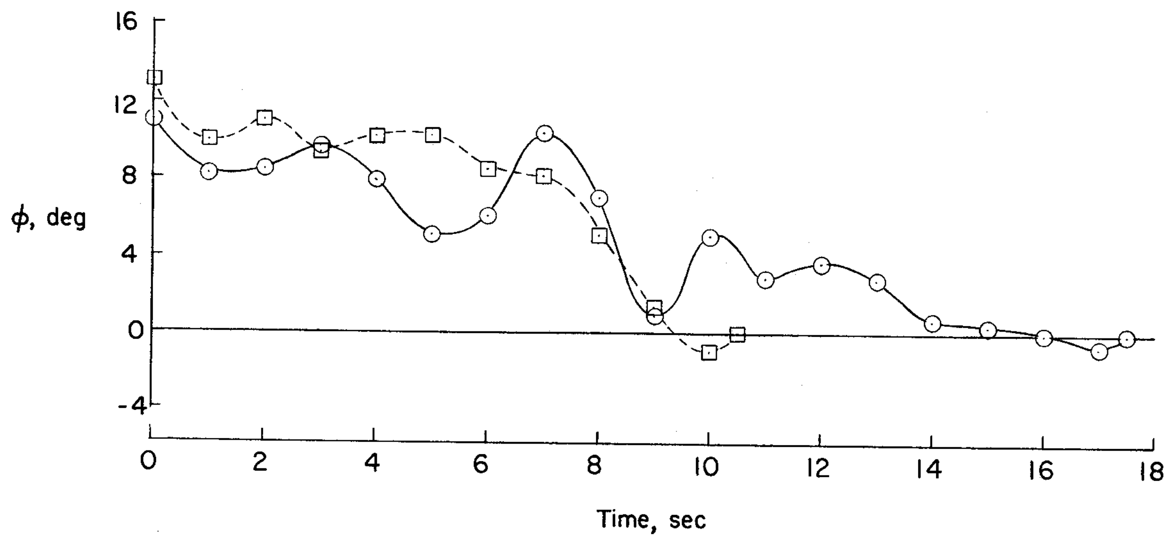


(a) Yaw.

Figure 3.- Time histories of pitch, roll, and yaw in a swing-around maneuver at low altitude. Velocity, 12 knots.



(b) Pitch.



(c) Roll.

Figure 3.- Concluded.

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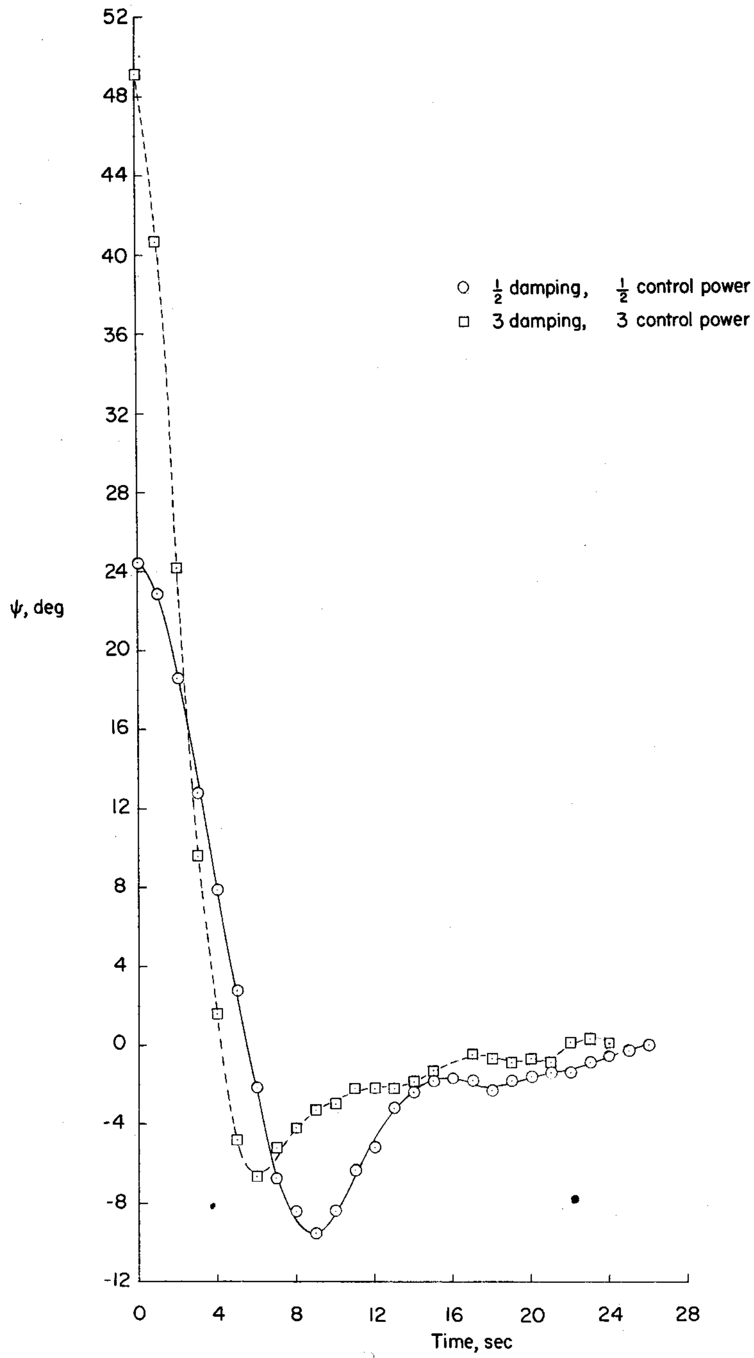
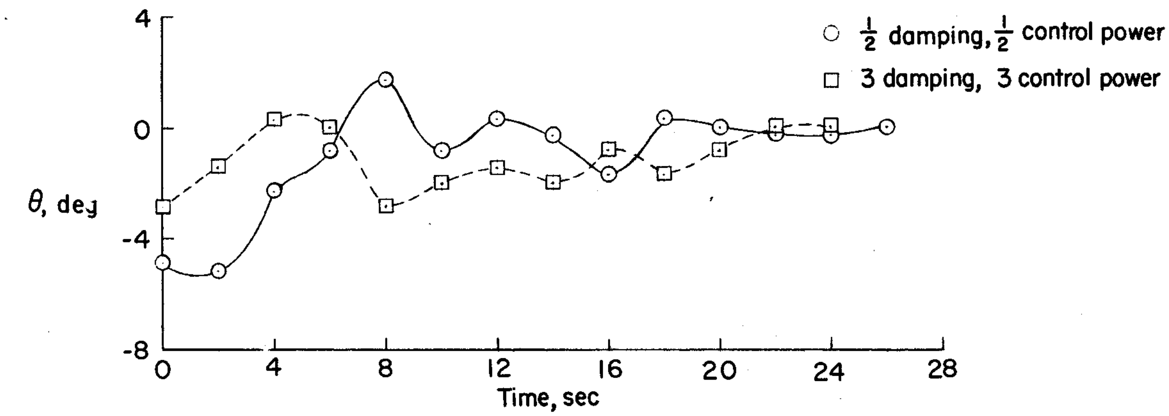
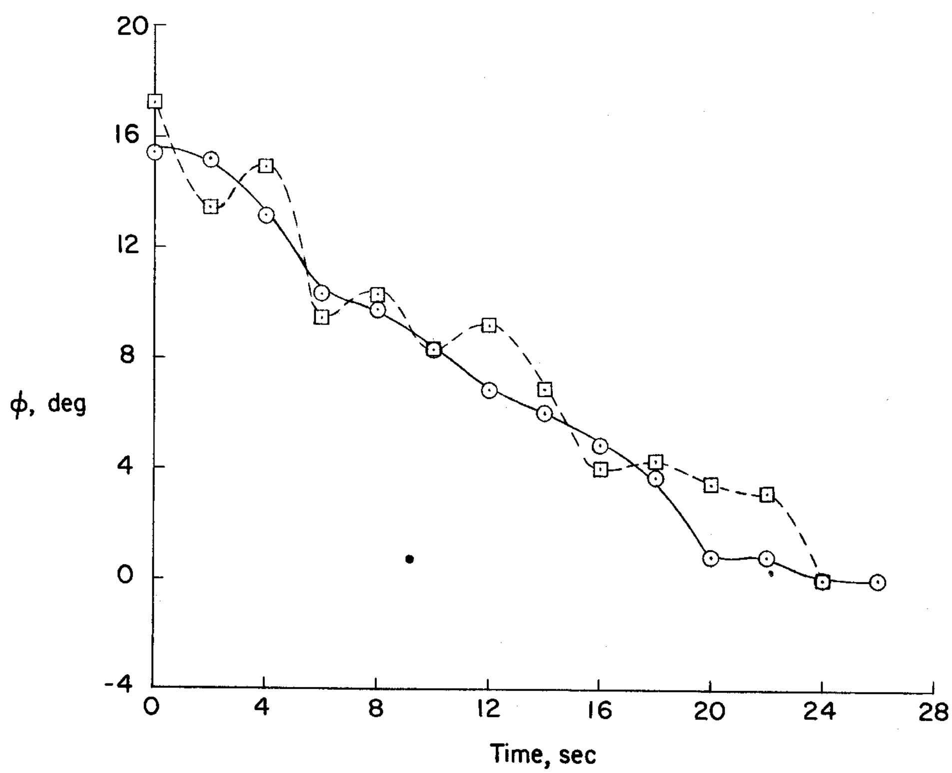


(a) Yaw.

Figure 4.- Time histories of pitch, roll, and yaw in a pop-up and swing-around maneuver at low altitude.



(b) Pitch.



(c) Roll.

Figure 4.- Concluded.

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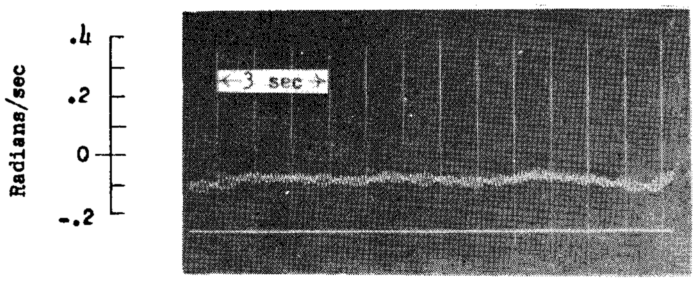
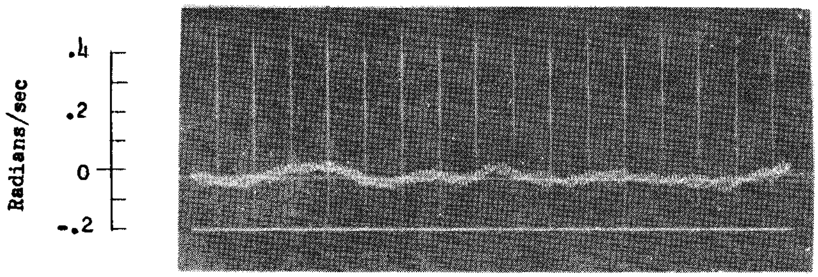
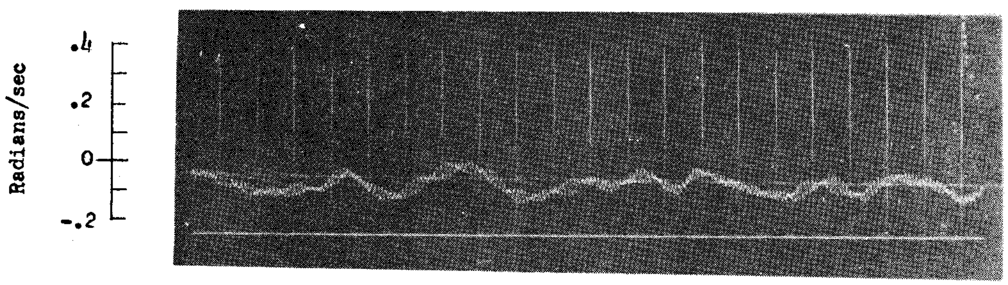


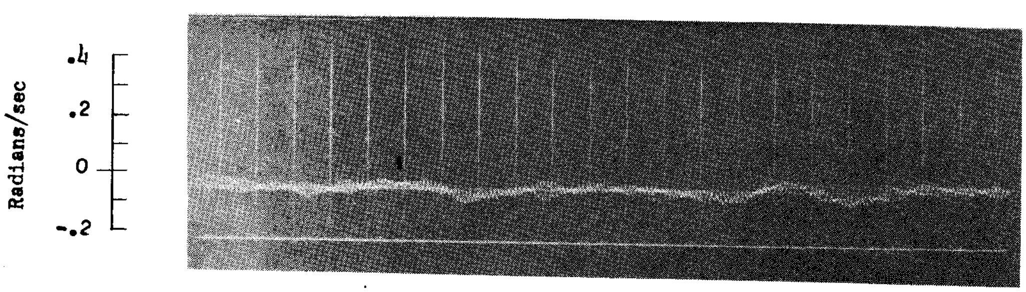
0° heading with respect to wind



90° heading with respect to wind



180° heading with respect to wind



270° heading with respect to wind

Figure 5.- Typical yaw-velocity time histories at four headings.